DOCUMENT RESUME

ED 055 807 SE 012 072

AUTHOR	Kastner, Jacob
TITLE	Nature's Invisible Rays, World of the Atom Series.
INSTITUTION	Atomic Energy Commission, Oak Ridge, Tenn. Div. of Technical Information.
PUB DATE	70
NOTE	50p.
AVAILABLE FROM	USAEC, P. O. Box 62, Oak Ridge, Tennessee 37830 (Free)
EDRS PRICE	MF-$0.65 HC-$3.29
DESCRIPTORS	*Atomic Theory; *Instructional Materials; Measurement Techniques; *Radiation; *Radioisotopes; Reading Materials; Resource Materials; *Secondary School Science

ABSTRACT

This booklet is one in the "World of the Atom Series" for junior high school students and their teachers. It describes the sources, methods for detection, and useful applications of the invisible radiation that occurs naturally on earth. Numerous photographs are included throughout the text. (PR)

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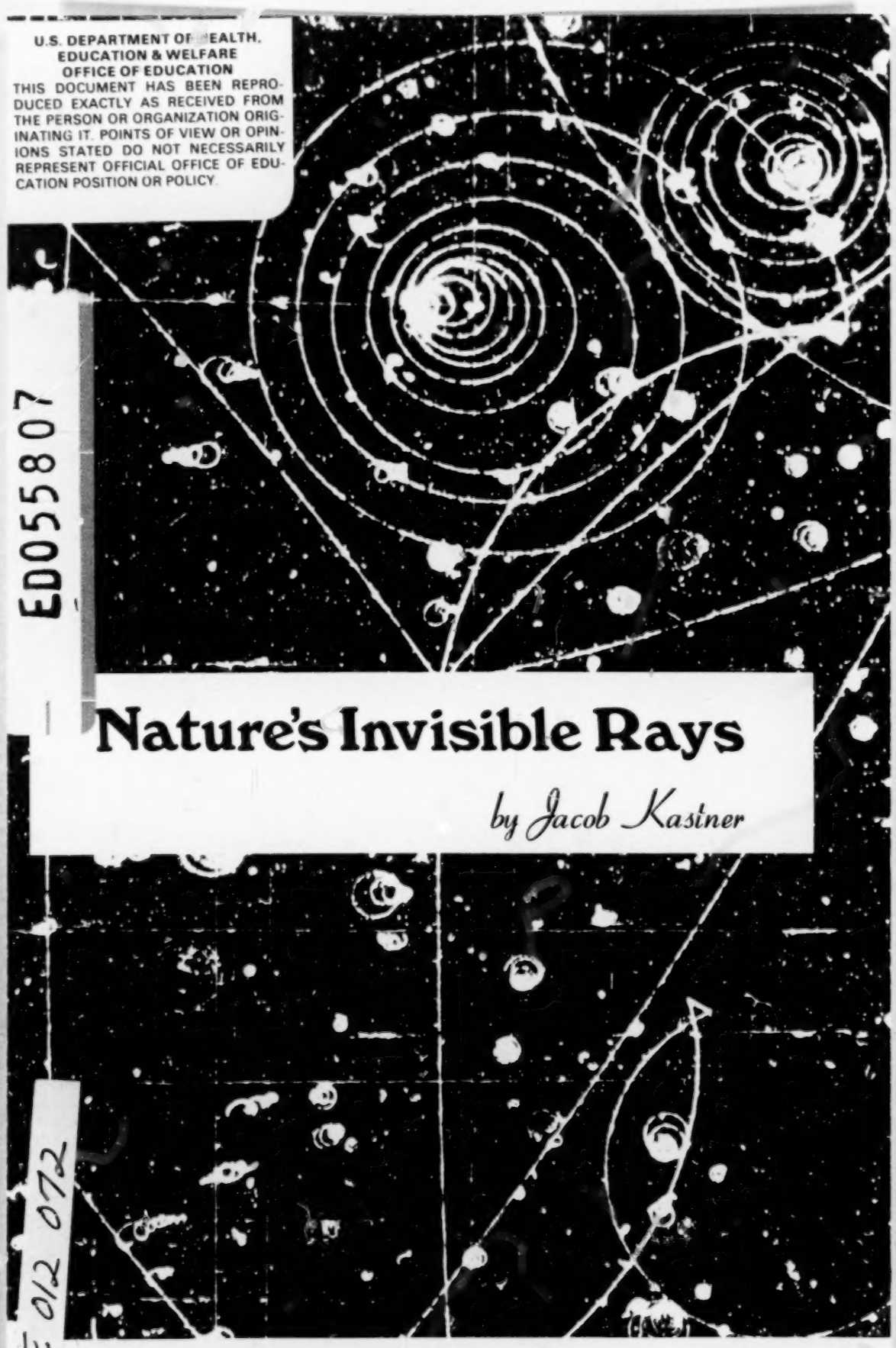

Nature's Invisible Rays

by Jacob Kastner

SE 012 072

The Author

Jacob Kastner received his Ph.D. in physics from the University of Toronto and has specialized for many years in radiation and radioactivity research. He was formerly a research physicist for the National Research Council of Canada and for the General Electric Company, and was director of research for the Picker X-Ray Corporation. He is now senior physicist in the Radiological Physics Division at Argonne National Laboratory in Illinois. Dr. Kastner is conducting research on measurement of background radiation levels in Lake Michigan and elsewhere, and on the effects of plant growth and seasons on natural radioactivity.

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THE WORLD OF THE ATOM SERIES

Foreword

This booklet tells about the invisible radiation that occurs naturally on earth. It is one in a series for junior high school science students and their teachers. The series describes the many exciting fields of nuclear energy.

Edward J. Brunenkant

Edward J. Brunenkant, Director
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UNITED STATES ATOMIC ENERGY COMMISSION

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United States Atomic Energy Commission
Division of Technical Information
Library of Congress Catalog Card Number: 70-606955
1970

Nature's Invisible Rays

by Jacob Kastner

WE'RE ALL IN THE SAME BOAT!

The scientists in the little boat have no fishing poles but they still hope to catch something—an occasional glimpse of nature's invisible rays! Of course, if they're invisible we can't glimpse them but at least we can observe their tracks, provided we're clever enough to build the proper detector.

The old saying, "He's so thick-skinned he doesn't know when he's being insulted", has applied to living things since their existence on this earth. In addition to visible light, plants and animals have always been exposed to invisible penetrating rays.* These could and did damage the living cells by stripping electrons from the cells' atoms, that is, converting them to *ions*, and thus interfering with the cells' normal functions.

Now right here I'm going to come to a screeching stop and start explaining a few things. Many occupations have their own language, as anyone knows who tries to translate a doctor's prescription! So if you're going to understand and enjoy what I'm going to tell you about what's going on around us, I'd better do some translating.

Scientists measuring cosmic rays on Lake Michigan. (See the chapter "Experiments Are Fun" that begins on page 26.)

*A collective noun for rays is radiation.

What are electrons? We know that atoms join together to form molecules. They often stick together very tightly and require outside energy to force them apart. When atoms change from a looser to a tighter arrangement, they give off energy in the form of heat, electricity, etc. For example, when coal is burned, carbon unites with oxygen to form carbon dioxide and heat. The reverse is also true, of course. When atoms are to be separated from each other, energy from the outside is needed to do the job.

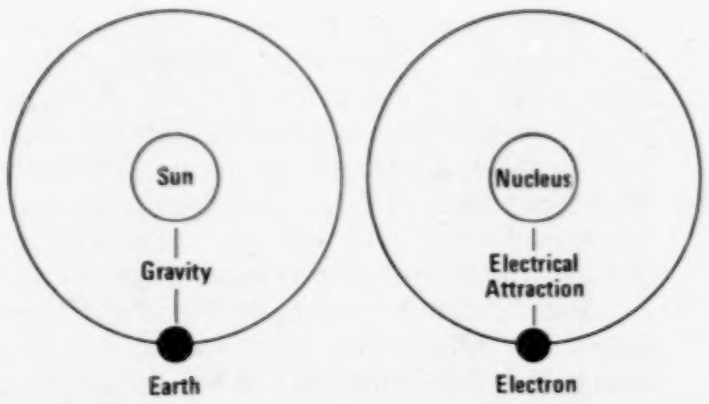
How are atoms attached to each other? What are their bonds? The answer comes from electricity.

For centuries man has known that when amber is rubbed with a cloth it becomes electrically charged and can pick up bits of straw or paper. The Greek word for amber is *elektron* and if a substance is repelled by the charged amber it is negatively charged; if attracted it is positively charged.

Static electricity and flowing electricity *(current)* are both forms of *electrons*, or negatively charged particles. When the electrons are stationary, or static, they are attached to the atom. These can be pulled off, leaving the atom positively charged; sometimes the atom acquires extra electrons and then becomes negatively charged. When the atoms join to form a molecule, they share electrons. Living cells are made up of such molecules.

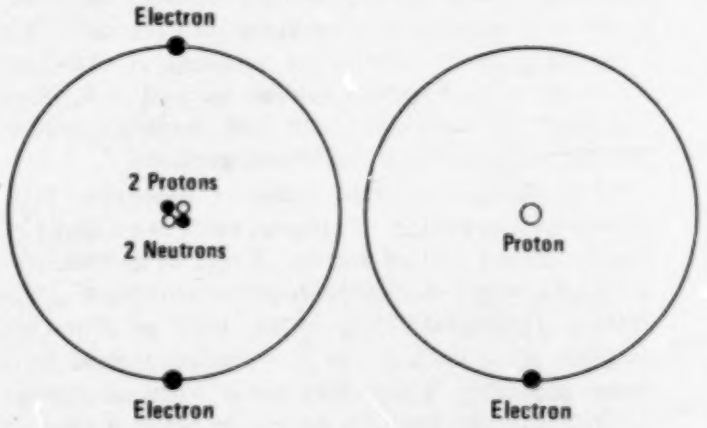
Let's go back to the atom. If we describe the electron as a bit of negative electricity, the rest of the atom must be positive to keep it from flying away. The hydrogen atom is our simplest atom and its positive nucleus is called a *proton*. The diagram shows the comparison between gravitational and electrical attraction.

Other atoms, such as oxygen, are more intricate since they are made up of more

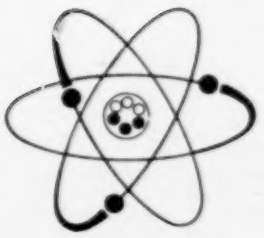


protons and electrons (equal numbers) in each case. The number of protons in the nucleus determines the kind of chemical element we have; for example, oxygen has 8 protons, and nitrogen, 7.

To make life a little more complicated, the nuclei of most atoms also contain some extra weight in the form of neutral particles called, amazingly enough, *neutrons*. Two atoms of the same chemical family (having the same number of protons) are called *isotopes* if they only differ by how "fat" (heavy) they are, that is, by how many neutrons they have in their nuclei. The name isotope comes from the Greek *isos* meaning same and *topos* meaning place (or the same place in the chemical table of elements).



A helium atom (left) and a hydrogen atom.



LITHIUM
Atomic Number-3
Atomic Weight-6 or 7
3 Electrons
3 Protons
3 or 4 Neutrons

Isotopes are atoms of an element distinguishable by their weight.

LITHIUM
Atomic Number-3
Atomic Weight-8
3 Electrons
3 Protons
5 Neutrons

Some atoms are so heavy, they get "excited enough" to lose weight suddenly.* They can do this in many ways; and you also have to remember that, as Einstein stated, matter (which has weight) and raw energy are really interchangeable. Thus, many atoms in their excitement will give off rays consisting of particles of matter and/or bundles of energy.

Such unstable atoms are called radiation active or *radioactive*. The bundles of raw energy are called *photons*.† When the photons come from the nucleus we call them *gamma rays*; when they result from a rearrangement of the outside electrons, they're called *X rays*. This is like worrying about a man's origin—is he English or Australian? It doesn't really matter; his behavior is what counts.

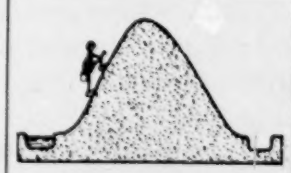
The invisible ionizing radiation, which has been part of the environment of plants and animals over millions of years, is made up of just such particles of matter or bundles of energy.

---

*Each chemical element has one or a few preferred atomic arrangements of protons, electrons, and neutrons. These stable isotopes contain an equal number of protons and electrons and the same or a somewhat greater number of neutrons. Atoms with an excess of protons or neutrons are said to be in an "excited" or unstable state and undergo sudden changes to preferred isotopic arrangements.

†A photon is often called a *quantum* (little package) of radiation. It behaves more like a cloud of energy than a ball of matter. *X rays* or *gamma rays* are high-energy, short-wavelength electromagnetic radiation (photons). Only when such photons are emitted by a nucleus are they called gamma rays. More generally, X rays may result when an excited orbital electron loses its energy or when a charged particle suffers sudden change in speed.

Water in pond is "stable". It expends no energy



Water can be carried uphill and its energy level raised

As it runs downhill it gives off energy and reaches a stable state

Atom is stable. It does not expend nuclear (atomic) energy

Atom can be bombarded with "atomic" particles and its energy level raised. Atom is now radioactive

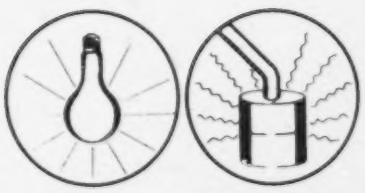
As it disintegrates it gives off energy in the form of radiations and reaches a stable state

Its interference with these living cells has generally been so small that it has not been noticed. It is only within the last 100 years that man realized that life on earth was continually being bombarded.

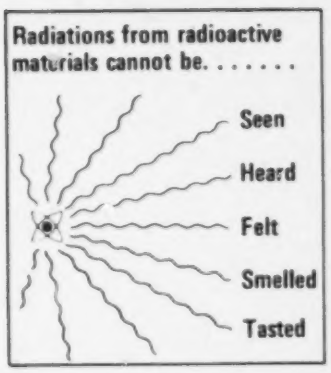
This little book has been written to give you an idea of the kind and amount of this radiation, where it comes from, how we measure it, and why we investigate it, especially since it has been ignored for most of man's existence.

There's More to the Sun Than Meets the Eye

The girl in the picture is getting more than she bargained for in the form of external radiation exposure. Besides the ultraviolet photons from which she hopes to develop a tan (an effect inside the skin), she is being bombarded by even more penetrating radiation, both from the earth and from outer

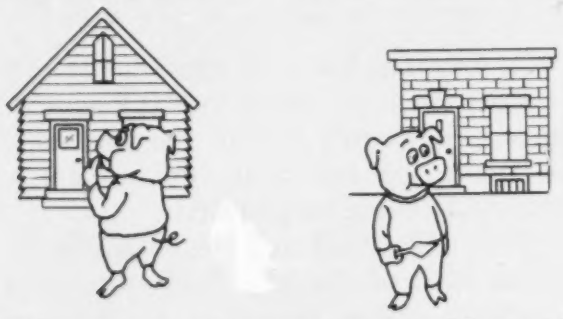


Light radiations can be seen | Heat radiations can be felt



space. She can't feel it because there are no nerve endings deep within her body. Furthermore, there are few lasting effects since the body is pretty good at repairing this minor internal damage, which might be compared with a tiny sunburn.

Most of the earth's background radiation consists of gamma rays or X rays, which result mainly from the radioactive decay of unstable potassium,* thorium, uranium, and other radioactive elements in the soil. These elements are found in minerals nearly everywhere. There may even be disadvantages in having a brick and concrete or granite home. Dr. William Spiers of Leeds, England, one of the world's foremost experts on natural radiation, points out that the intensity of gamma rays from radium in the brick may provide as much as three times the exposure one might expect from a wooden house.



These levels of exposure are 50 to 100 times less than that which is considered quite safe for man. There are certain areas on the world's surface, such as in Brazil or India, where the very low safety limits set by our government experts are actually exceeded.

*Natural potassium, like many other elements, is an elemental family composed of several members (isotopes), which have different weights. In this case a fat isotope, ^{40}K, is the unstable one and occasionally leaves the family after giving up a piece of itself (a beta particle) to become part of another family, the calcium family.

X rays from these minerals, led Henri Becquerel to the discovery of natural radioactivity in 1896.* He had been investigating a certain salt of uranium that, as he had shown some years earlier, glowed brilliantly under the action of ultraviolet light. A bit of this salt, after exposure to light, was wrapped in black paper and placed near a "sandwich" consisting of a sheet of silver and a photographic plate. Becquerel found, by accident, that the photographic plate was affected, or fogged, regardless of whether the salt had been exposed to light. He concluded that uranium produced penetrating radiation similar to that discovered by Wilhelm Roentgen† a year before. Roentgen had generated X rays‡ artificially by directing electrons into a metallic target.

Henri Becquerel.

Following Becquerel's discovery it was soon determined that the atoms of such heavy metals as uranium or thorium are constantly, though very slowly, breaking down and giving off *alpha rays*§ and *beta rays*,¶ as well as X rays in the process.

Wilhelm Roentgen.

That part of our external exposure which comes from outer space can be traced to the

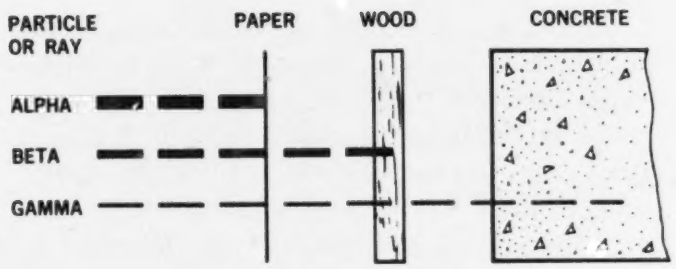
*Becquerel won a Nobel Prize in Physics in 1903 for discovering radioactivity in uranium.

†Roentgen won the Nobel Prize in Physics in 1901 for discovering the X ray.

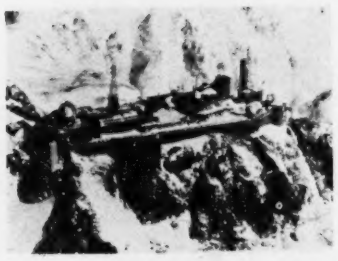
‡X rays that are machine produced are properly called "Roentgen rays".

§Alpha rays are streams of alpha particles, which are positively charged and consist of 2 neutrons and 2 protons (really a helium nucleus). Alpha radiation is the least penetrating of the three common forms of radiation (alpha, beta, and gamma). It is so weak that it can be stopped by a sheet of paper, and it is dangerous only when inhaled or swallowed.

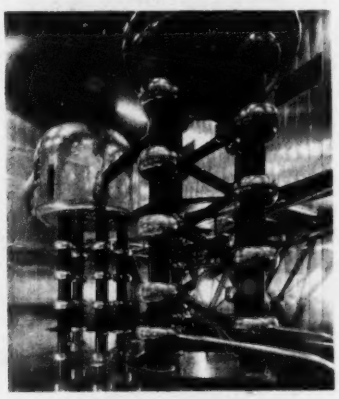
¶Beta rays are streams of beta particles, which are identical with electrons when negative, and when positive are called positrons.



Alpha, beta, and gamma penetrations.



Cosmic-ray research is often conducted at high altitudes such as at the Pic du Midi Observatory in the High Pyrenees in France.



This Cockcroft-Walton generator provides the first stage of particle acceleration for an accelerator, or atom smasher, at the Argonne National Laboratory in Illinois.

steady rain of charged particles (*cosmic rays*) moving at nearly the speed of light and falling upon our planet at all times and from all directions. These particles are just the nuclei of ordinary atoms stripped of their electrons; they are for the most part the nuclei of hydrogen atoms (protons).

The property of cosmic rays that sets them apart from all other kinds of radiation and accounts for the extraordinary role they have played in the development of modern physics is the very large individual energies of their particles. Before their discovery, the highest energy particles known were those given off in the natural decay of radioactive atoms.

Now why are physicists interested in such high-energy particles? Because they have the capability of smashing atomic nuclei into bits. The hope is that man, by studying the details of the crash, may understand the forces that hold the nucleus together. In fact, before man-made machines* were developed, scientists were looking at the pieces of the collision of cosmic rays with oxygen and nitrogen nuclei in our atmosphere. This naturally occurring debris accounts for most of the

*Such a machine is the 200 billion electron volt (Bev) particle accelerator being built in Batavia, Illinois. There are 10 accelerators in this country and 17 in foreign countries with energies greater than 1 Bev.

radiation exposure of our sunbathing young lady. A large part of this radiation consists of photons (electromagnetic radiation), covering a fairly large spread of energies, and a small but important part are high-energy neutrons.*

These neutrons crash into molecules of our atmosphere until all the particles have the same energy, which is the same as saying that they end up at the same temperature. At this slow speed they are easily captured by nitrogen atoms to form radioactive carbon (carbon-14) or super-heavy radioactive hydrogen, called tritium (^{3}H).† The breakdown or disintegration of these isotopes contributes little to the external exposure because their radiation is not penetrating. However, in gaseous form these materials can be swallowed or inhaled and, like alcohol or tobacco, can be dangerous if taken in large quantities. This brings us to the unavoidable problem of the intake of radioactivity from food and drink.

Brazil Nuts and Cereals

Whenever scientists bring up the question of internal exposure due to natural radioactivity in food they immediately think of Brazil. Not only because of the very high

*Neutrons are uncharged particles with mass slightly greater than that of a proton. The isolated neutron is unstable and decays with a half-life of about 13 minutes into an electron and a proton. Neutrons sustain the fission chain reaction in a nuclear reactor. Half-life is the time in which half the atoms in a radioactive substance disintegrate to another nuclear form.

†Nitrogen-14 captures a neutron to become nitrogen-15, which, in a relatively short time, ejects a proton to become carbon-14. Some of the heavy nitrogen atoms break up into tritium and other light atoms.

gamma-ray activity of the soil, which exists in certain areas of Brazil as well as India, but also because of the Brazil nut with its very high radioactivity—about 14,000 times that of common fruits. Of course the Brazil nut is exceptional and by no means characteristic of nuts in general. Cereals are also relatively high—perhaps as much as 500-600 times that of fruits, which have the lowest concentrations of natural radioactivity. The table points out pretty clearly that it pays to keep away from rich foods for more than one reason.

RELATIVE ALPHA ACTIVITY OF FOODS

Food Stuff	Relative Activity
Brazil nuts	1400
Cereals	60
Teas	40
Liver and kidney	15
Flours	14
Peanuts and peanut butter	12
Chocolates	8
Biscuits	2
Milks (evaporated)	1–2
Fish	1–2
Cheeses and eggs	0.9
Vegetables	0.7
Meats	0.5
Fruits	0.1

Actually the table discusses only the alpha activity of foods and this tells nothing about the radioactive potassium contribution. All muscle-building foods contain potassium, and we must eat to live. Recent surveys indicate that for most populations the radioactive potassium in our muscles provides 10-20 times the internal exposure of any of the other radioactive materials, such as radium, carbon-14, or tritium, which are retained in the body.

Whenever scientists are concerned with the internal exposure to man from radioactivity retained in his body, they also have to study the human food chain. They need to

follow the way in which the earth's radioactive chemicals are absorbed into plants and animals, which, in turn, are eaten by humans. This mechanism provides for depositing, distributing, and removing the chemicals in our organs. It has been found, just as in the case of Brazil nuts, that many plants and animals retain certain chemicals to a greater degree than others, and in this way develop a specific pathway for a particular radioactive element to get into the human body.

For example, radium is found in different concentrations throughout the human food chain. Studies have been made in a great number of mammals—mice, rats, rabbits, dogs, pigs, and man. Approximately 1 to 10% of the radium taken in is retained, mainly in the skeleton and a small amount in cartilage and thyroid.

A very clear transfer was that of radioactive lead, which concentrated in the organs of arctic caribou. These animals serve as the basic diet of some Eskimos whose bones were found to contain high concentrations of this element.

Clear, Cool Water

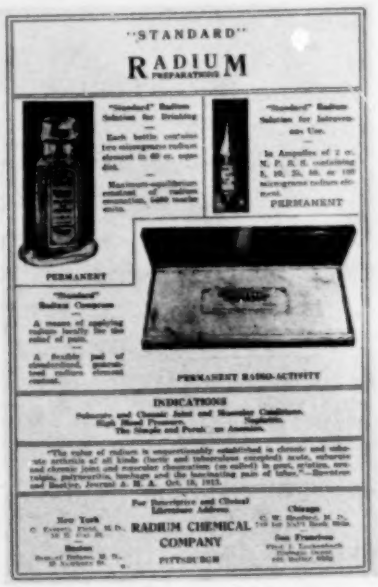
With the exception of some of my friends who claim it rusts pipes, most people believe that there is virtue in clear, cool water. There is also something else in well water. A study in progress in the midwest began with the discovery, 20 years ago, of the high natural radioactivity in the drinking water of several municipal water supplies. In 1955 the radioactivity was found to come from radium, which had been dissolved out of the soil along with the other more common salts, such as calcium, magnesium, etc.

The deep wells of Joliet, Illinois, for example, have 300 times more radium than

Chicago's lake water. Eventually analyses were carried out all over the country.

The water from the wells of Maine has 3000 times as much radium as the Potomac River, which serves Washington, D. C., our capital. Of course, Maine's radioactivity is mild indeed when compared with that of some springs in Kansas and Colorado, or Jachymov, Czechoslovakia, where the concentration is 10,000 times greater.

Amazingly enough it has been less than 50 years since such quantities of radium in water were considered a great asset. Radium and thorium were used as medicines for all sorts of diseases. Fortunately it only took a generation for most doctors to realize that radium chemically resembles natural calcium so much that it tends to pile up in our bones and do serious damage. However, there are still places in the world that offer the advantages of bathing in radioactive mineral springs. Several years ago, I ordered mineral water in Milan and noticed that the label on the bottle boasted about the radioactive contents and the merits of such radioactivity in curing many gruesome illnesses.


"STANDARD"
RADIUM
PREPARATIONS
"Standard" Radium Solution for Drinking
"Standard" Radium Solution for Intravenous Use.
PERMANENT
PERMANENT
"Standard" Radium Compress
PERMANENT RADIO-ACTIVITY
INDICATIONS
RADIUM CHEMICAL COMPANY
PITTSBURGH

Advertisement for radium medicines in the early 1900s.

WHO CARES AND WHY?

A quick answer to this question is that scientists want to know and therefore care, and medical doctors and hygienists* need to care. However, before discussing why these groups care about radiation, let me explain briefly that it is important to know the quality and quantity of the radiation to which man is exposed because of the damage that radiation can do to biological matter.

What Harm Can It Do?

In general, radiation damages the complex molecules within a cell, and interferes with the cell's chemical machinery to the point, in extreme cases, of killing it. The delicate structure of the *genes*† is particularly vulnerable to the impact of radiation. A cell that is not killed may be so damaged that it cannot duplicate itself, that is, undergo mitosis.

If a cell is of a type that normally doesn't divide, the destruction of the mitosis machinery isn't fatal to the whole organism. The fruit fly *Drosophila*, which, as an adult, has very few cell divisions occurring in its ordinary body cells, can survive radiation doses a hundred times greater than that needed to kill a man.

Hermann J. Müller won a Nobel Prize for showing that radiation can cause mutations in Drosophila.

In humans, however, there are many tissues whose cells must undergo division throughout life. Hair and fingernails grow because of cell division at their roots. The outer layers of skin are steadily lost through

*Persons who deal with the establishment and maintenance of health in an individual or group.

†Genes are hereditary units, contained in each body cell, which determine the characteristics of an unborn child. Genetic effects of radiation are those that can be transferred from parent to offspring. Somatic effects of radiation affect only the exposed individual.

rubbing and are replaced through constant cell division in the deeper layers. The same is true of the linings of the mouth, throat, stomach, and intestines. Blood cells are also continually breaking up and must be replaced.

How Much Is Too Much?

If radiation kills the mechanism of division in only some of these cells, it is possible that those that remain intact can divide and eventually replace or do the work of those that can no longer divide. In that case the radiation damage is relatively mild and eventually disappears.

Sometimes the radiation is so weak that the damaged cell can still divide, but it has been so changed, or mutated, that the cell and its descendants no longer function normally in the body. It is in this way that radiation may cause skin cancer, leukemia, and other diseases. It is this type of bodily, or somatic, cell damage that may arise from the natural radiation background; although the probability, like the background's strength, is extremely low.

Mutations can be produced in the sex cells too. Since these cells are passed on from parent to child, succeeding generations are affected and not merely the parent. Actually, where sex cells are concerned, the relatively mild effect of mutations is more serious than the drastic one of nondivision. A fertilized ovum that can't divide eventually dies and does no harm; one that can divide but is altered may subsequently give rise to a defective child.

That is why scientists maintain that there is no threshold* in the genetic effect of

*A threshold is an amount of radiation below which there is no effect. A threshold dose is the smallest amount of radiation that will produce an effect.

radiation and no "safe" amount of radiation, insofar as genetic effects are concerned. However small the quantity of radiation absorbed, mankind must deal with a corresponding increase in the genetic load.* Although the damage may not be apparent, once a sex cell's structure is altered by radiation (or any other agent), it has a better chance of unfavorably affecting some as yet unborn person.

Background radiation accounts for much less than 1% of the spontaneous mutations that take place naturally. The others arise out of chemical effects, random heat (molecular vibration)† effects, and so on. In the light of the relatively small effects resulting from our natural radiation environment, let us now explore the motivation of those key groups that were mentioned earlier.

Who Wants to Know?

Scientists want to know both for the sake of knowing and for the helpful applications that the knowledge can provide. Much of the information about natural radiation comes from investigations that were completely unconcerned with human environmental questions. For example, Dr. Henry Faul, a geophysicist at the University of Pennsylvania, points out that it would be difficult to discover why anyone needs to know the answers to such questions as "How old is a rock?", "How old is man?", and "How old is the earth?". Yet they have been asked over and over again since the dawn of human society.

Nuclear techniques were used to determine the 2,000,000-year age of this early ancestor of man. Zinjanthropus is the name given to this skull, which was discovered in Africa in 1959.

*This is the burden of unwanted genes that each animal has.

†When molecules vibrate because they are warm or hot, there is always the possibility of a wild movement of the atoms that results in the breaking of a chemical bond.

It's Been a Long Time

The only reliable method of measuring such very long periods of time is based on this discovery by Pierre and Marie Curie in 1898: Some atoms are radioactive, that is, they change naturally into other atoms at regular and constant rates. We call the original radioactive atoms *parent* atoms, and the atoms they disintegrate into *daughter* atoms. When we compare the populations of parent atoms to daughter atoms and perhaps even great-grandparents to great-granddaughters for very long-lived elements like uranium,* we can make a pretty good estimate of say, the age of the earth, which is 4.5 billion years.

Oceanographers bring aboard a 50-gallon seawater sampler from the ocean depths as part of their research of radioactivity in the sea.

How Fast (Slow) Is the Ocean's Bottom Piling Up?

Radioactive beryllium-10 (^{10}Be) with a half-life of 2.7 million years is produced by cosmic rays and has been detected in marine deposits. From this activity scientists deduced that some of the ocean bottom formed from dissolved chemicals in the seawater at a rate of about 2 millimeters (a little less than $\frac{1}{8}$ inch) per million years!

The Age of Man

If we want to determine the age of man, we look for a natural radioactive material that decays at a much faster rate. When we find a piece of wood in some ancient structure, we can measure the amount of carbon in it. We determine how much of it is carbon-14 (^{14}C), half of whose atoms decay every 6000 years. We then calculate back to the time when the radioactivity from the ^{14}C was the same as it is now in living wood (where it is continually being replenished from the atmosphere).

*Most of its atoms live for billions of years.

U.I 20

Who Got There First?

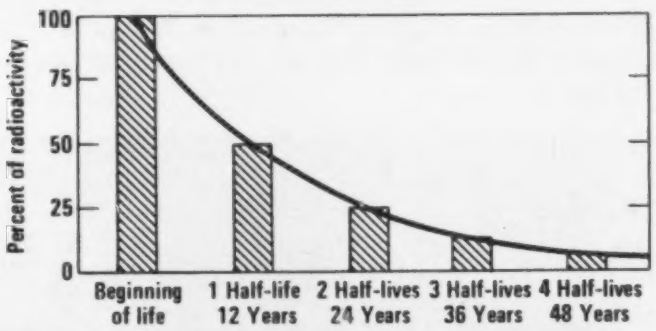
With the aid of ^{14}C it has been possible to date human living sites from many points in the western United States. The first appearance of these sites, about 11,500 years ago, apparently occurred at a time when a land bridge was open from Asia to America over what is now the Bering Strait. An ice-free passage extended from this bridge through present-day Alaska and western Canada to the United States. This may have been the route taken by the first immigrants to America; these were mammoth-hunters, who made the characteristic flint *Clovis* arrow and spear points.

A Clovis *arrow point chipped from flint by the earliest men on the American continent. The photograph is actual size.*

About 11,000 years ago, the Clovis people had spread across the area of the United States and into Mexico. They may have been the ones who killed most of the mammoths and then gradually assumed the characteristics of the *Folsom* culture. The Folsom people were bison-hunters, and for a long time were thought to have been the first inhabitants in America. With ^{14}C it finally was possible to place these two cultures in proper order—the Clovis first—and to associate them with major natural changes, especially the advance and retreat of glaciers across the continent.

How Old Is that Imported Liquor?

When your dad offers that expensive imported liquor to his guests, he can be sure he wasn't cheated about its age. The U. S. Treasury Department maintains a sensitive analytical laboratory that can measure the alcohol's minute amount of radioactive hydrogen (tritium—half of whose atoms break up every 12 years). The customs duty paid by the importer is related to the age of the liquor.



Radioactive decay pattern of hydrogen-3 (tritium). Half-life is the time in which half the atoms in a radioactive substance change to another form.

The tendency to deposit fat seems to be inherited, and breeding stock with low fat content can be selected, using muscle-seeking potassium-40 to show the proportion of muscle in each potential parent. Above a steer is placed in a whole body counter.

That's Not Muscle, That's Fat!

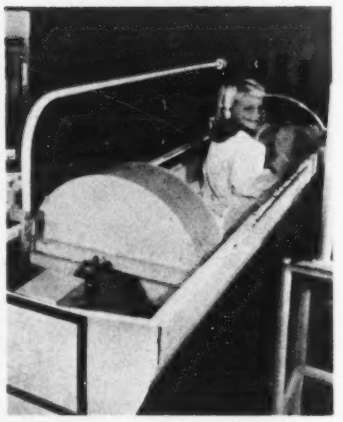
Biological scientists and medical practitioners alike have used the body's natural radioisotopes to help them learn about humans and animals in a nondestructive way. As mentioned before, muscle contains a lot of potassium where fat tissue has none. Potassium-40 (^{40}K), a radioactive potassium isotope, emits gamma rays that are so penetrating they can pass through a 250-pound athlete or even a cow.

An important medical application is the relationship of muscle-fat ratios in humans with disease. Highly sensitive whole body detectors in rooms with thick iron walls (to cut out the earth's gamma rays) are now available in most of the major biological

institutions and hospitals of the world. The meat industry has even carried out some preliminary experiments to establish the possibility of purchasing cattle on the basis of muscle-fat ratios determined in this way. Maybe someday we'll see such iron rooms set up in every stockyard!

Scientists will seize upon any source of information to further their knowledge. Thus even man's bad habits are used in this way. It recently has been shown that cigarette smoke contains a naturally occurring radioactive element, polonium-210. Studies have demonstrated that more of this radioelement is found in the lung and other soft tissues of cigarette smokers than those of nonsmokers.

Still another technique is based on the tiny amounts of radium remaining in the bones of humans who were exposed to radium poisoning before its hazards were generally understood.



This girl in the chute of a large whole body counter has just had the natural radioactivity in her body counted.

Dogs about to be examined in a whole body counter.

Examples of such people are the men and women in the U. S. and Switzerland who painted watch dials with radium paint, which

made the dials glow in the dark. (These workers often used their lips to keep a fine point on their brushes.) The bones of these victims are an important source of information on bone growth as well as on the effect of radium on human bone.

Radium-dial painters in a watch factory in 1922. Almost all these employees have been identified, and the living ones participated in a study at Argonne National Laboratory to determine how much radium had accumulated in their bodies.

The time it takes to build up bone cells and to reabsorb them is an important clue to the process of bone growth. It is possible to estimate this turnover time of human bone by measuring the fraction of a bone section still labeled with radium even as much as 40 years after it was acquired.

Doctors and hygienists have to know what happens in nature before they can judge what's really harmful. Only by knowing the amounts and variations of natural radioactivity can such people make intelligent interpretations of the data they get in their work.

Health Physics

Before a nuclear-powered electricity generating facility is constructed on a site, the management usually calls in radiation safety officers (called health physicists in the United States) to make measurements of the

natural background and to identify the types of radioactivity present. This then provides a threshold or base against which to check future plant operations. Thus, if the plant's discharge (effluent) cooling water is found to contain more radioactivity or other isotopes than that present in the intake from the local stream, prompt measures can be taken to improve the purification technique. Of course, the local public health people might insist that the water coming out of the plant be cleaner than when it went in.

This, for example, is the situation in a German Westphalian Nuclear Research Establishment near the Rhine River. The Rhine is so filthy that fish have trouble living in it. In recent years a white whale lost its way from the North Sea and was sighted upstream in the Rhine River. Even though it was an air breather, the poor thing was having great difficulty keeping its blowhole free of the muck from the river. Nevertheless, the effluent water from Westphalian reactors is amazingly free of contaminants.

Another factor that is of great concern to radiation safety people is the possibility of discharging radioactivity into the air. The general method used in sampling the atmosphere is to draw air through a filter at a known rate for a known period of time. The filter radioactivity is then measured. The problem in this simple technique is that there are days when the air is heavy with the daughters of the radioactive gas, radon; the concentrations of their natural and short-lived radioisotopes can be as much as 500 times the maximum permissible concentration of the long-lived isotopes in the nuclear fuel, which should not be allowed to escape from the nuclear plant.

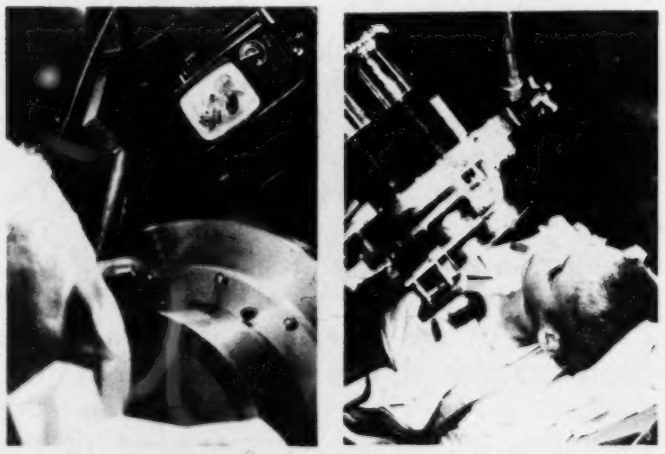
So you see the need for the public hygienist to know "what comes naturally"; he can then carry out the proper detective work.

Network of towers on the Atomic Energy Commission reservation near Richland, Washington, used by atmospheric physicists in measuring quantity, concentration, and dilution of radioactive materials in the atmosphere.

Medicine

Medical doctors today depend a great deal on the use of artificial radioactive materials as aids in diagnosing or pinpointing illnesses. For example, radioactive iodine, ^{131}I, behaves chemically in the body just like its non-radioactive isotope, iodine-127. The penetrating gamma rays of the ^{131}I permit observation from outside the body with some form of radiation detector. The thyroid gland, located at the base of the neck, controls the way in which our body converts food to energy. It is also very efficient in trapping iodine from the blood stream. So a doctor will give a person, suspected of having thyroid trouble, a drink containing a tiny amount of the radioactive tracer ^{131}I and then measure how much of it is retained by the person's thyroid.

For tracer experiments such as these it is often necessary to know the natural invisible rays that might hide what one is looking for.



Measuring radioiodine uptake in the thyroid gland with extremely small amounts of a mixture of iodine-131 and iodine-125. On the left is a small television set that is mounted in such a way that good viewing requires that the head be kept in the desired position. On the right is another view of the child in position for thyroid uptake study.

HOW CAN YOU TELL?

This question is particularly suitable for the presence of nature's radiation because it is so small. This is the same question you would ask a fine primitive hunter if he told you that a leopard had just passed down the trail and that the leopard had injured its right front paw. The leopard's path, like radiation, can only be detected by its spoor. Spoor (or spur) comes from the Saxon word for track. German scientists still refer in this way to the tracks developed in photographic film after the passage of nuclear radiation.

When the numbers of rays are as small as is generally the case in nature, the trail becomes very difficult. One must either wait a long time and build up evidence or set a very sensitive trap that will be triggered to give an alarm. In the following section we will outline some of the ways that can and have been used to count and test the strength of the elusive radiations to which we are continually exposed. We will also describe some ingenious experiments.

Radiation Doesn't Tickle But Fortunately It Takes an Awfully Good Picture*

Very shortly after Becquerel's discovery of radioactivity using a chunk of uranium and a photographic plate, Roentgen used gelatin emulsion, or film, to photograph X rays and thereby make "radiograms". (Incidentally, in correct scientific language a photograph is the camera and the resultant picture is a photogram. Compare with telegraph and telegram.)

*At least not at these levels. Dr. Norman Frigerio, a radiobiologist at the Argonne National Laboratory in Illinois, suggests that some people can detect an intense source by a tingling of the skin.

The history of radiation detectors has followed the history of physics. Ever since its discovery, studies of radiation effects on matter have been made. At first only solid matter, crystalline particularly, was studied in the early laboratories. It was soon learned that the passage of radiation through certain chemicals, like zinc sulfide (ZnS), would give rise to flashes of light that could be seen with the naked eye.

Lord Ernest Rutherford.

Lord Ernest Rutherford* and his students spent hours in a darkroom looking into a small eyepiece coated with ZnS, which he called a spinthariscope. They observed and counted the individual flashes of light (scintillations) resulting from the impact of alpha rays. Today we are able to amplify these light flashes electronically and record both their number and intensity. In this way we can measure the rate of exposure fairly easily, whereas a film emulsion can only add up the radiation over a period of time.

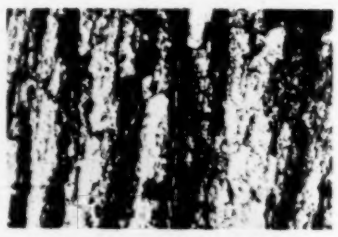
Other solids, crystals, and glasses are also able to store radiation energy. When subjected to heating or ultraviolet irradiation, these solids give off visible light that is a measure of the stored radiation energy. Of course, many different kinds of exposure can cause the same total light. One therefore needs additional evidence before being sure it was, to use our comparison, a leopard and not a tiger that passed down the trail.

An application that is most suitable for such solid, luminescent, or light-producing dosimeters† is the evaluation of the natural

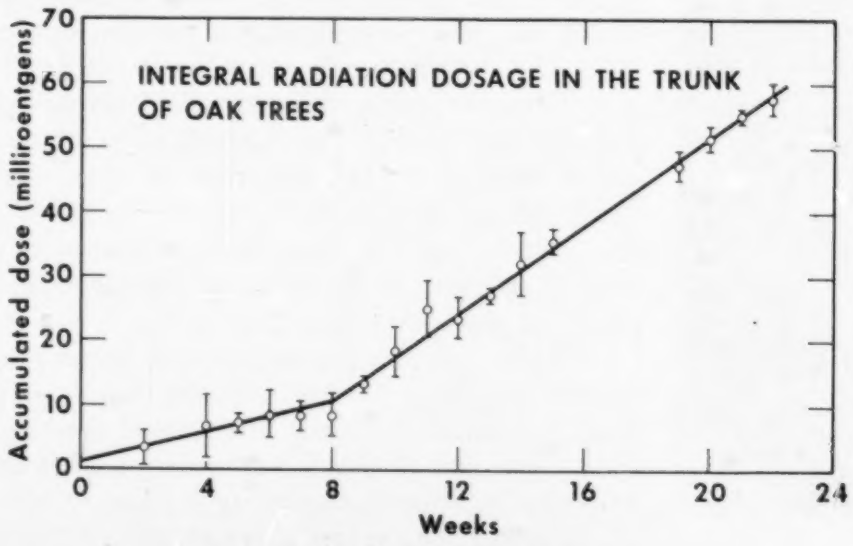
*Lord Rutherford received the Nobel Prize in Chemistry in 1908 for formulating the theories of radioactive disintegration of elements, the nature of alpha particles, and the atom's nucleus.

†Dosimeters, or dose measurers, are energy storing solids.

radiation as related to plant growth.* The advantage of such solids is their relative resistance to weathering, mild temperature changes, humidity, etc. Such a study was carried out recently in which a number of such solids were imbedded in the bark of oak trees, and every 2 weeks, several dosimeters would be read to establish whether the background rate had changed. The figure clearly demonstrates the marked break in rate when the leaves began to grow on the trees in the spring.



Lithium fluoride dosimeters (left) embedded in the bark of an oak tree.



Accumulated gamma exposure dose.

This principle of using radioactivity's energy as its own giveaway has been quite useful in dating old pottery and establishing the age of layers of the ocean's bottom. We recently heated a piece of core drilled from the ocean floor 2 miles deep in the Pacific, and sure enough it gave off blue light.† The core proved to contain uranium and thorium that had been radiating for 100,000 years.

*Such a study is called radiation ecology.

†Blue light is given off as a result of heating a material that has stored energy. This light is called thermoluminescence.

As laboratory techniques became more sophisticated and physicists learned how to create vacuums, they began to study gases. Some of these experiments were the basis for the discovery of X rays. *Ionization** of a gas is one of the most common and sensitive indicators of the passage of radiation. This is the basis of the well known Geiger counter as well as the less sensitive but very accurate ion chamber.

A liquid detector that grew out of watching bubbles form in a glass of beer led to a Nobel Prize in physics in 1960. Donald A. Glaser, an American physicist, pointed out in 1952 that bubbles will form along the track of a charged particle that has passed through a superheated liquid. The high density of the liquid makes it far superior to the old-fashioned cloud chambers that exhibited jet-like vapor trails for lazy, slow particles, but were inefficient for tracking the kangaroo-like trail of super-energetic radiation.

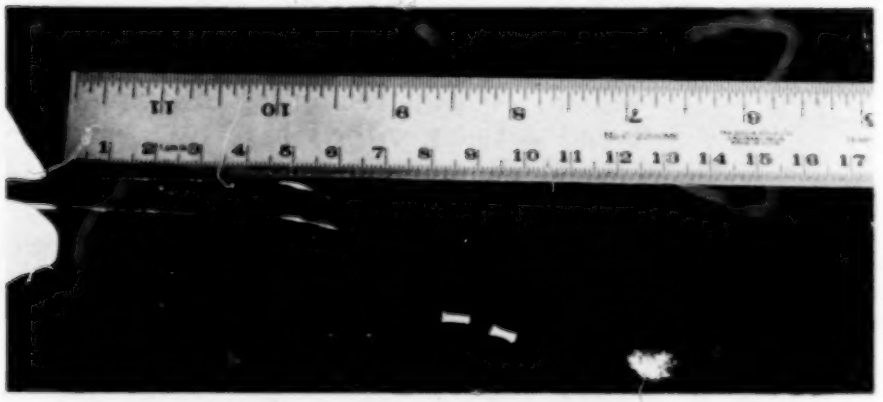
On the left is a photograph of tracks in a bubble chamber, which tells the story of a major collision. Contrast the size of the tiny solid detectors in the figure on page 27 with Argonne National Laboratory's 12-foot bubble chamber. The world's largest, the chamber will contain 25,000 liters (6500 gallons) of liquid hydrogen and weigh 3500 tons.

Experiments Are Fun

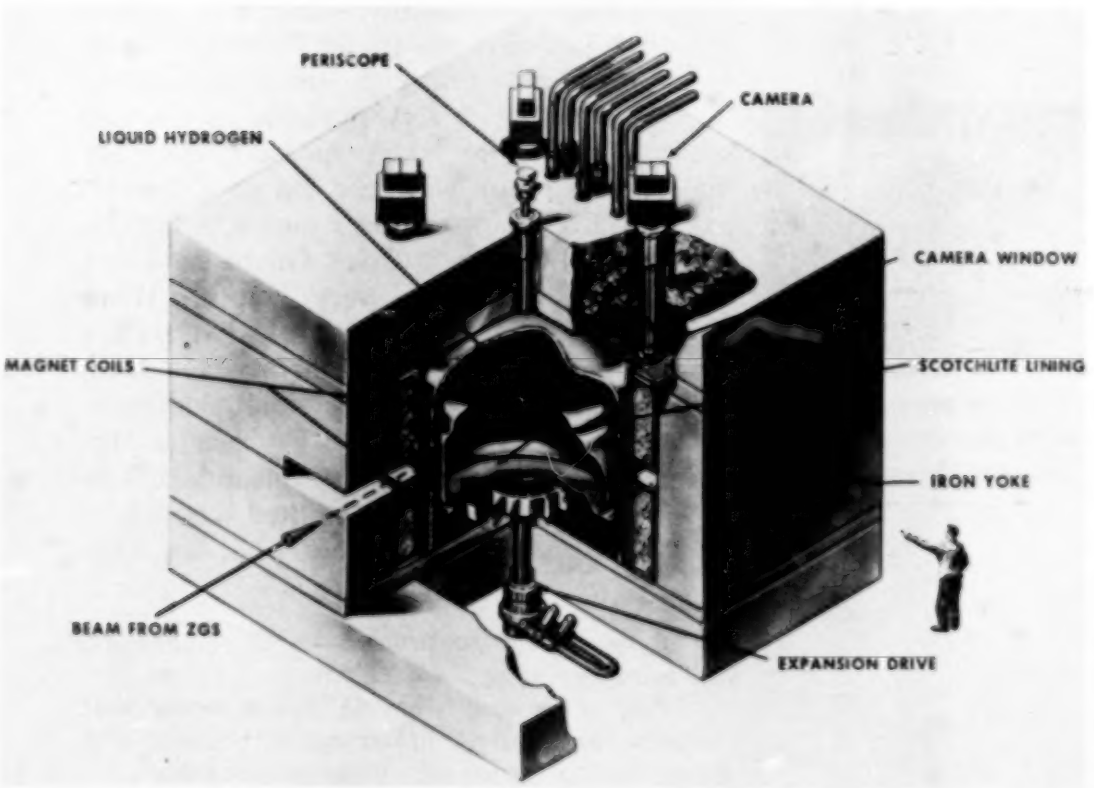
The nosy experiments that we scientists perform to spy on nature are fun. This is because the results not only satisfy our curiosity, but the experiments themselves often give us an excuse to get outdoors and sneak up on nature in her home territory. Let

*Ionization is the splitting off of electrons from a neutral atom, which is then left positively charged.

me tell you about some of the experiments we have carried out and some we are doing right now.



Solid state detectors (above) and 12-foot bubble chamber (below).



When I tried to requisition a small aluminum boat with an outboard motor, I was asked whether I also needed a fishing pole and what kind of beer I preferred. But why *did* we want to go boating on the lake? The answer was simply to get away from land and its high content of gamma-emitting materials. For several decades, efforts have been made to separate the natural gamma-ray background exposure into earthborn and non-earthborn parts. Thirty feet of water is enough to shield all the gamma radiation from the earth. Thus, if sensitive measurements are made a mile or two from shore over fairly deep water, one should discover how much of the gamma radiation comes from outer space.

When the English scientist Dr. William Spiers visited us earlier and learned that we were using a very sensitive ionization chamber to measure the earth's gamma-ray background (and therefore, willy-nilly, a non-earth contribution), he urged me to go "fishing". Needless to say, I didn't need too much persuasion.

Extremely sensitive environmental radiation measuring system.

The system* is very portable as you can see in the picture where measurements are being carried out with the aid of a "shavepak"† plugged into a car's cigarette lighter. The men of the U. S. Coast Guard stationed at Lake Michigan were very helpful. There were several complications in what would otherwise be fairly straightforward measurements. We had to use a small aluminum boat (see picture on page 1) because the gamma rays from the potassium and radium in the materials of a large painted wooden or steel ship would overshadow what we were

*Designed and constructed by Dr. F. Shonka, St. Procopius College, Lisle, Illinois.

†This is a small vibrating power supply that converts the cigarette lighter's direct current into alternating current for use with an electric shaver.

trying to measure. Even the radium in the instrument dials on the bridge of the Coast Guard cutter gave more current than we were looking for.

The cutter took us and our little boat out on Lake Michigan so far that the air would shield us from the gamma-emitting soil. Thus, if we were separated by 10 meters of water from the nearest earth (beneath us), we needed to have at least 10,000 meters of air between us and the shore. (Water is about 1000 times as dense as air.)

But what about radon gas carried by the prevailing wind from shore to us? To account for this contamination (radon daughters emit gamma rays when they decay), we carried on board ship several large collapsed balloons. The balloons were each enclosed in a large glass bottle, about 50 centimeters in diameter, and attached by a simple valve system to the narrow neck of the bottle. When one of us blew up a balloon, he acted as a pump to collect a substantial sample of air at the time and place of our measurements.

These samples were later measured for radon content. (Of course, we had checked our individual body contribution of radon.) The air was passed over finely divided and very cold charcoal or carbon that trapped the radon gas, and the alpha particles from the decaying radon could then be counted.

We were also concerned about the purity of Lake Michigan water; after all, soluble salts from surface runoff and human wastes do end up in the lake. We collected 10-gallon samples of lake water for analysis. Nowadays the analysis of gamma rays from weak radioactive sources is so sensitive that we were able to detect the presence of debris from the Chinese bomb tests! The main contamination in our water was a slight trace of potassium-40

together with an even smaller trace of bomb-produced cesium-137.

After correcting our lake measurements for the small contributions from the contaminated air and water, we were able to tell the world the value of the cosmic-ray component at 41°N. (53°N. Geomagnetic) and 540 feet above sea level. For comparison with previously derived values, everyone adjusts their figures to sea level and the equator. Values calculated in this way will be smaller because there is more atmosphere at sea level to thin out the primary cosmic rays. Furthermore, fewer cosmic rays enter the earth at the equator because of the earth's magnetic field, which tends to guide charged particles to either pole.

The cosmic-ray contribution at Chicago is about a quarter of the total radiation exposure on land. We generally quote the cosmic-ray value as about 4 microroentgens* per hour.

Having measured the gamma-ray and charged particle components of the cosmic rays, what about the other major product of cosmic-ray interactions in our atmosphere, namely, neutrons? It was known that there were much fewer of these than of gamma rays or charged particles. However, each neutron is as heavy as a hydrogen atom and, if energetic, can knock out of place the hydrogen atoms that make up most of our cells. It became a challenge to try to measure the exact number and energy distribution of these neutrons, which hit every square centimeter of area about once every 2 minutes.

At first, we carried out our measurements in the laboratory, but we discovered that

*A roentgen is a unit of radiation that is the amount of gamma rays required to produce 2 billion pairs of ions in 1 cubic centimeter of dry air under standard conditions (0° Centigrade and 1 atmosphere of pressure). 1 μr/h = 2000 ion prs. per cc.

people in a building 200 yards away were generating neutrons periodically with an accelerator. A few minutes a day of this extra contribution was more than enough to match a week's background!

With the cooperation of the City of Chicago Water Department we located our apparatus at one of Chicago's water intake cribs offshore in Lake Michigan. The crib proved to be an ideal location for measurements because it is far enough from shore to be free of terrestrial and artificial radiation. You can see what the detector for "fast" (energetic) neutrons looks like in the picture.

Another type of detector was used to measure very slow, thermal, or room temperature neutrons. We made up half-pint cans containing special photographic emulsions that were loaded with the isotope lithium-6 (^{6}Li). This isotope has the property of being able to capture a thermal neutron and then splitting into two new atoms, tritium and helium. The splitting (explosion) shows up in the film as a small star or blotch, and these can be counted. In the picture one of us is removing a can that has been on the bridge at the crib for 6 months. Thanks to the U. S. Coast Guard, we could also put some cans on navigation buoys 7 miles out in the lake.

At this stage of the experiment we are relatively satisfied with our measurements of neutron flux or total intensity. But to be sure of distribution we'll need another few years.

At the water intake crip, scintillation counting equipment for recording neutron bombardment is adjusted by the author.

A can containing cosmic-ray detecting materials is removed from a bridge on the water intake crib.

FROM MINE TO MOON

Of one thing we are sure—radiation of various types and quantities is everywhere. It is only a question of the proper technique to determine what kind and how much.

Uranium miners.

Ever since the discovery of radioactivity, it has been obvious that uranium mines would be sources of invisible rays to which the miners would be exposed. Recently, laws have been passed that established fairly strict controls on their exposure. Sensitive instruments specially designed to estimate the radioactive concentration are under development.

One of these is a beanie-type, battery-operated propeller that sucks air through a small piece of filter paper. The miner wears this on his helmet. When he's through working for the day, the filter paper is sandwiched with a piece of plastic for a while. The radioactive dust on the paper gives off alpha rays that bombard the plastic and weaken it so that when soaked in a suitable chemical, such as lye, small, etched pits are formed. These can be counted, either by hand or by machine, and the number of pits is an indication of how well the mine is being ventilated.

You Can Get Away from It All

Not all mines exhibit a high level of radioactivity. In fact, quite the contrary. Mines of common table salt are often very free of radioactive impurities and deep enough to shield out most of the radiation from outer space. Such mines in Ohio and Texas have been used by researchers to do experiments that require a radiation-free environment. I know a graduate physics student who means it when he says "back to the salt mines".

A delicate experiment to determine the stability of the proton was carried out 2 miles

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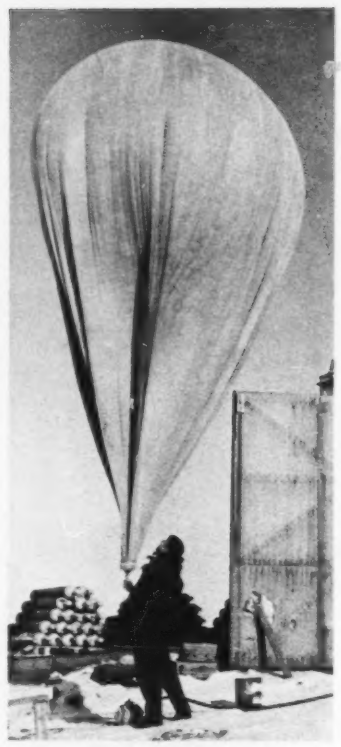
below the earth's surface in a gold mine in South Africa. So far, it has been established that if the proton is unstable at all, its average lifetime is almost a billion billion billion years.



A scientist launches a balloon that will carry radiation detection equipment.

Up, Up, and Away

As man rises out of the mines and leaves the earth's surface he leaves the earth's radiation but is more exposed to impacts from space sources, since he no longer has the benefit of the shielding of the earth's atmosphere. This winter we were fortunate to fly our apparatus on a DC6 at 20,000 feet above Miami. The U. S. Department of Commerce's Environmental Science Services Administration (ESSA) has Weather Bureau planes that have been used for a decade to spot and follow hurricanes. We obtained, in 6 hours of flying at this altitude, as much data as in 2 weeks on the ground!

The question arises: What will be the exposure to the crew and passengers of the proposed supersonic transport that may fly at 70,000-80,000 feet? It doesn't look too bad for an hour's flight under normal conditions. However, during a solar flare the sun spits out

This 570,000-mile-high solar flare occurred on June 15, 1958.

an intense burst of protons. Furthermore, the earth's magnetic field is distorted so that more of these charged particles can arrive at the earth without deflection. Under such conditions there is a good possibility that the pilot may be required to take evasive action and drop to 40,000 feet. Otherwise the passengers will be subjected to as much radiation in 1 hour as we now receive on the ground in a month!

The World's Biggest Belt—Earth's Magnetic Personality

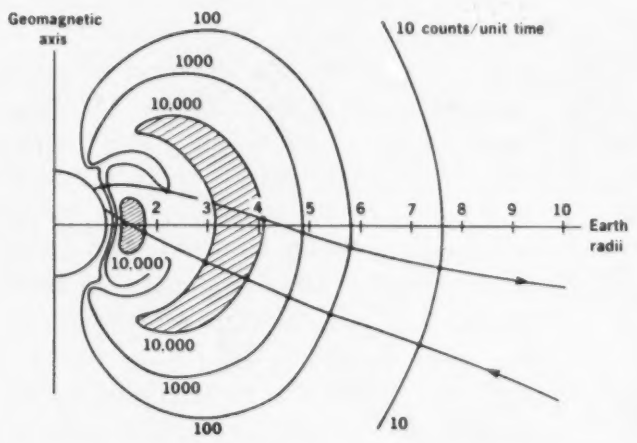
The Coast Guard Cutter East Wind *near Greenland on the 1952 Van Allen expedition.*

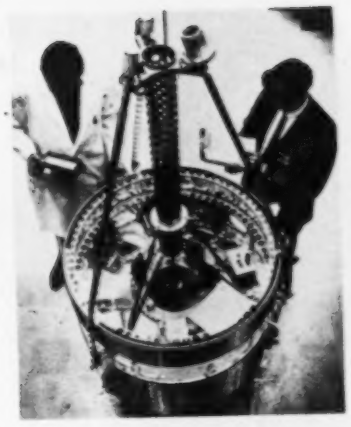
As man keeps going up out of our atmosphere and into space, he will no longer experience exposure from earth's radiation. More and more of the radiation will be clean cosmic rays, including some flurries of radiation originating on the sun. Some electrons and protons are trapped in the earth's magnetic field and constitute belts of radiation surrounding the earth. Professor James A. Van Allen discovered these belts in 1958 when he sent up some Geiger counters by rocket as part of the Explorer 1 satellite. Later it was determined that these belts begin about 500 miles above the earth's equator and extend out about 40,000 miles.

Aesop's Bullies

One of Aesop's delightful fables tells of the argument between the sun and the wind as to who was the stronger. The test became one of determining who could make a man take off his coat. Of course the sun's warm personality won over the wind's gruff brute force. Well, Aesop wasn't aware that the sun and the wind are one and the same bully out in space. The sun's wind consists of powerful invisible rays that wash the earth and moon and swirl millions of miles around and past the planets. In this case it's the earth's

During the summers of 1952-1955, James A. Van Allen and a research group from the University of Iowa launched instruments high into polar skies to measure low-energy cosmic rays deflected into the auroral regions by the earth's magnetic field. They did this by firing a small rocket from a high-altitude balloon, which had risen to 60,000 feet. The rocket, fired upward through the balloon and using the atmosphere below as a launch pad, could easily reach 50 miles. On the left above are James A. Van Allen (right) and the rocket, which was carried high aloft by a balloon. On the right above are a rocket and balloon ascending from the East Wind. *Below is Van Allen's famous map of the radiation belts derived from the GM tubes carried by Explorer 4 and Pioneer 3 satellites.*





Pioneer 6, a deep-space probe now in orbit around the sun. From such an orbit it can radio back information about solar radiation.

One of 6 astromonks, brought to the Los Alamos Scientific Laboratory in New Mexico for space radiation environment experiments, is unloaded from a plane by an animal psychologist.

magnetic personality that protects most of its atmosphere from a lot of needless exposure.

In space, of course, there is no blanket of atmosphere to shield man from direct bombardment. We will have to provide him with his own radiation shield. The uncertainties concerning the intensity and kind of radiation exposure will need to be eliminated before we can provide the proper protection for a man remaining in space. Much of the incident radiation energy is dissipated in shielding material by ionization—the electrons in the shields carry away the energy harmlessly.

Good spacecraft radiation shields must therefore have a lot of electrons in a pound. The best element for this purpose is hydrogen, which has almost twice as many electrons per kilogram as do all the other elements. Thus, weight for weight, it's a better shield. Since hydrogen will remain a liquid in the cold of outer space (and is also a rocket fuel component), perhaps we shall see our spaceships with double walls containing liquid hydrogen somewhat like inside-out thermos bottles.

What's Up, Doc? Green Cheese?

Now, what happens when we arrive at the moon? Radiation conditions there ought to be similar to those experienced by our supersonic transport planes near the top of our atmosphere. Cosmic rays will come barrelling in from space (with no atmosphere to shield the astronaut), smash into the moon's soil, and generate neutrons near the surface, which will come boiling back out to pester the poor humans who have the gall to settle on the surface. There is one important difference, however, between the top of our atmosphere and the moon's topsoil. There is no nitrogen to gobble up thermal neutrons (and generate

LE 40

The lunar samples above are glass spherules of various colored crystals. The largest is 0.4 millimeters in diameter.

^{14}C). Thus the flux or intensity of thermal neutrons could very well be very much higher than on earth. Since thermal or very slow neutrons are easily captured by stable elements, making them radioactive, this environment may prove a real hazard to spacemen, who wish to stay on the moon for any length of time. Their clothes may need to be lined with lithium or boron. These elements are very opaque to slow neutrons. At this writing we have not yet had a final interpretation of the information resulting from the Apollo-11 or -12 moon landings.

An additional but less important contribution to man's radiation environment on the moon is the lunar radioactivity. Like the radioactivity from the earth, it comes about mainly from basalt and granite regions containing potassium, thorium, and uranium. The lunar soil composition was established in a preliminary way by the Russian experiments on their Luna-10 satellite, which orbited the moon in March 1966.

Since then, of course, man has managed the colossal achievement of bringing back samples of the moon's surface. These were checked for their gamma-ray emission in a specially designed radon-free room, 15 meters below the ground. As a result of these measurements, we now know that the concentration of thorium and uranium in these moon samples is much like that of similar rock on earth. The radioactive potassium concentration, however, proved to be much lower in the lunar surface material than for earth rocks or even meteorites. Furthermore, there were definite amounts of radioactive aluminum, sodium, scandium, and other radioactive elements, which are not naturally present on earth.

Their presence on the moon is explainable on the basis that the lunar surface material

has been exposed to cosmic radiation for at least several million years, thus generating these unusual radioisotopes, which are only artificially available on earth.

Moon's Pearly Light?

An interesting sidelight to the moon's continual bombardment by radiation from space is the very reasonable suggestion by scientists of the Westinghouse Electric Corporation that the energy stored during bombardment on the night (and cold) side of the moon is released by the sun's rapid heating in the form of visible light.

It is well known that many imperfect and impure crystalline materials, such as quartz or fluorite, will trap (in impurity centers*) the electrons resulting from ionizing radiation and later, when heated rapidly, release these electrons to recombine with ions and produce light. The light intensity is directly related to the total radiation exposure. This phenomenon is called thermoluminescence. It is the basis for a modern system of radiation dosimetry or exposure measurement, which has begun to replace the conventional film badge for radiation safety.

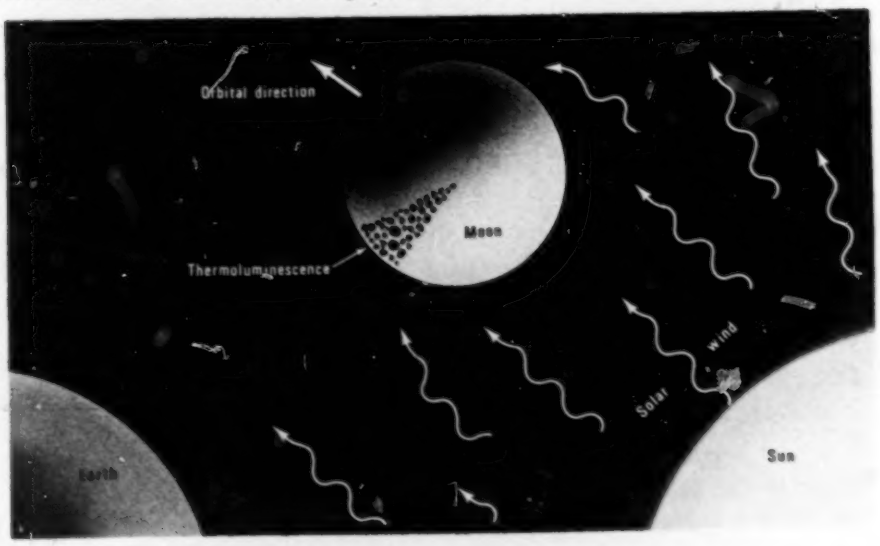
The Westinghouse scientists now estimate that the moon's thermoluminescent intensity may amount to as much as one-third of the reflected sunlight in the same region!

A thrilling prospect for a very practical application of the natural lunar radiation background is the possibility of using the energy trapped in the moon's soil during the lunar night. Moon settlers might well tap a vast storehouse of energy on the dark side of the moon. By the end of the lunar night, the bombarded material possesses 6 kilowatt

*An impurity center is usually a foreign atom not basic to the crystal—for example, a trace of iron in quartz or a trace of manganese in fluorite.

hours per pound—more energy than is stored in coal. The dust could be fed into an insulated chamber to generate heat for a lunar base or to produce electricity by heating a thermoelectric generator.

Thermoluminescence from the moon's surface occurs in the dawn region as the sun's rays warm up the meteorite rock, releasing energy trapped from the solar wind during the lunar night. Above, a meteorite glows with thermoluminescent light after being irradiated in a laboratory and subjected to temperature changes simulating conditions on the moon's surface at dawn.



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RELAX AND ENJOY IT

I started this little story by saying that life on this planet has always been exposed to radiation. In fact, it is said that it is the very existence of radiation that has produced the evolution of the myriad species we have today. It is certainly true that changes caused by radiation, which have become involved in natural selective forces, have developed men and animals especially fitted for survival in their environments.

The academic question always arises: Will genetic damage by radiation alter man? As we don't know, and there really isn't much we can do about it anyway, let's hope the changes, if any, will be for the better. Goodness knows we can certainly bear to be improved. The point is that, with the addition of sheer knowledge, man has the imagination to eventually control his environment.

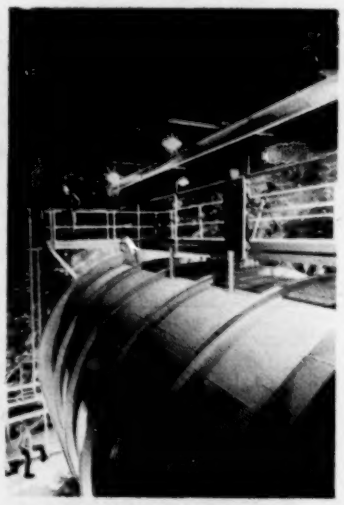
What We Don't Know Could Fill a Book

What we don't know is always infinitely more than what we know. All we can begin to talk about are experiments in the immediate future. As we do them and gain more knowledge, new frontiers open up.

You Can't Get Away From It

We are continually being washed by neutrinos from the sun. Neutrinos are almost weightless neutral particles, which penetrate matter so easily that the intensity of neutrinos on the night side of the earth is estimated to be only 10% less than the sun side. A very complex and sophisticated apparatus has been devised to detect these elusive "critters" but a great deal still needs doing.

Elaborate experiments have been planned under the Himalayas to gain the advantage of



Brookhaven National Laboratory's solar neutrino detector is located 4850 feet underground in the Homestake Gold Mine in Lead, South Dakota.

a mountain as an absorber. One experiment actually will consist of a 30-foot cubical room containing a scintillating liquid* and electronic light converters, which will be like television picture tubes 3 feet in diameter. These detectors will be serviced by frogmen! However, we need to know more about this wash of neutrinos; who knows—they may provide a communication system through the earth that won't depend on the weather or booster stations!

To know is satisfying, but learning to know is fun, and designing experiments to pin down information is even more fun than just learning. When you can leave the lab and investigate the world around you what more can you ask?

*A scintillating liquid detects the light flashes caused by radiation striking certain materials.

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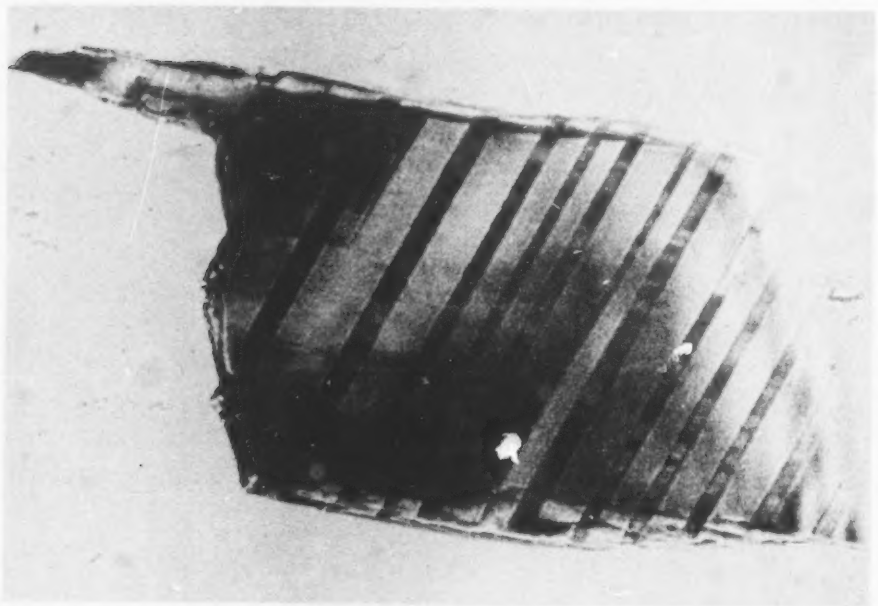
An electron micrograph of a moon rock.



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Printed in the United States of America

USAEC Division of Technical Information Extension, Oak Ridge, Tennessee

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